WPS5026

Policy Research Working Paper 5026

On Interfuel Substitution

Some International Evidence

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Development Research Group
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August 2009

Abstract

This paper estimates interfuel substitution elasticities in selected developing and industrialized economies at the national and sector levels. In doing so, it employs state-of-the-art techniques in microeconometrics, particularly the locally flexible normalized quadratic functional forms, and provides evidence consistent with neoclassical microeconomic theory. The results indicate that the interfuel substitution elasticities are consistently below unity, revealing the limited ability to substitute between major energy commodities (i.e., coal, oil, gas, and electricity). While the study finds some evidences of larger interfuel substitution potential in high-income economies as compared to that in the middle- and low-income economies in the industrial and transportation sectors, no such evidence is observed in the residential and electricity generation sectors or at the national level. The implication is that interfuel substitution depends on the structure of the economy, not the level of economic development. Moreover, a higher change in relative prices is needed to induce switching toward a lower carbon economy.

This paper—a product of the Environment and Energy Team, Development Research Group—is part of a larger effort in the department to study climate change and clean energy issues. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at gtimilsina@worldbank.org.

On Interfuel Substitution: Some International Evidence*

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JEL classification: C2; D4.

Keywords: Flexible functional forms; Normalized quadratic (NQ) cost function; Theoretical regularity

*We sincerely thank Erwin Diewert, Melvin Hinich, and Shahidur R. Khandker for their comments on an earlier draft of this paper. The World Bank Research Support Program provided financial support. The views expressed in this paper are those of the authors and do not necessarily represent the World Bank and its affiliated organizations.

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1 Introduction

The effects of output growth and changing fuel prices on the demand for energy depend on interfuel substitution and the substitutability of energy and other factors of production. Over the years, these issues have attracted a great deal of attention in a large number of energy demand studies, with most of these studies taking the approach of using a flexible functional form for the underlying aggregator function, following Diewert's (1971) influential paper. In fact, this approach to empirical energy demand analysis was pioneered by Berndt and Wood (1975), Fuss (1977), and Pindyck (1979). It involves specifying a differentiable form for the cost function, and applying Shephard's lemma to derive the resulting cost share (or input-output) equations. Using these equations and relevant data, one then could estimate the parameters and produce inferences about the demand for fuels (including those about the own- and cross-price elasticities as well as the elasticities of substitution).

Although the role of energy in the structure of production has been the focus of a large number of econometric studies, the evidence on interfactor and interfuel substitutability is mixed. For example, the early studies by Berndt and Wood (1975), Hudson and Jorgenson (1974), Fuss (1977) and Magnus (1979) all used time series data for a single country and found substitutability between energy and labor, but complementarity between energy and capital. Also, Fuss (1977), using Canadian data, found oil, gas and coal to be substitutes, but found no substitutability between each of these energy inputs and electricity. Moreover, Pindyck (1979), taking a similar approach to that used by Fuss (1977), used pooled time-series data for a cross section of countries and found energy and labor to be substitutes and also energy and capital to be substitutes, and not complements as earlier studies had indicated.

In this regard, it should also be noted that the results of most energy and climate change policy models, no matter whether they are partial equilibrium or general equilibrium type, are highly sensitive to elasticity parameters, particularly the elasticity of interfuel substitution. However, there also exists only limited literature estimating such elasticity parameters. Moreover, with the exception of a few sporadic local papers, there is still a huge void in the literature dealing with energy demand and interfuel substitution in developing countries. This study is expected to contribute in filling the literature gap by estimating interfuel substitution elasticities through the use of recent advances in microeconometrics.

Over the years, there have been a large number of other studies investigating interfuel substitution and the demand for energy — see, for example, Uri (1979), Considine (1989), Hall (1986) and Jones (1995), among others. The major contributions in this area, however, are quite outdated by now, since their data incorporate observations before the 1970s. Also, very few studies deal with energy demand and interfuel substitution in developing countries, probably due to the lack of reliable data at that time. Moreover, most of this literature ignores the theoretical regularity conditions of neoclassical microeconomic theory. However, as Barnett (2002, p. 199) put it, without satisfaction of the theoretical regularity conditions, "the second-order conditions for optimizing behavior fail, and duality theory fails. The resulting first-order conditions, demand functions, and supply functions become invalid."

In this paper we investigate interfuel (i.e., oil, natural gas, coal and electricity) substitution, using international time series data. In doing so, we investigate interfuel substitution for entire economies as well as within the industrial, residential, transportation and electricity generation sectors of these economies, since the structure of interfuel substitution is different for different sectors of use. Our objective is to improve our understanding of how economic growth, government policies, and the development and implementation of new technologies, will affect interfuel substitution and the demand for energy in the future. We use recent advances in microeconometrics, including duality theory and flexible functional forms. We minimize the potential problem of using a misspecified functional form by employing a well-known flexible functional form and provide inference, and also a policy perspective, using parameter estimates that (for the first time) are consistent with the theoretical regularity conditions of neoclassical microeconomic theory.

So far, the literature on energy demand and interfuel substitution employed locally flexible functional forms and, in particular, the translog, introduced by Christensen *et al.* (1975). See, for example, Fuss (1977), Pindyck (1979), Jones (1995) and Urga and Walters (2003). These forms provide the capability to approximate systems resulting from a broad class of generating functions and also to attain arbitrary elasticities of substitutions, although at only one point (that is, locally). However, although locally flexible functional forms provide arbitrary elasticity estimates at the point of approximation, there is evidence that these models fail to meet the regularity conditions of neoclassical microeconomic theory in large regions.

In this paper, we also use a locally flexible functional form to investigate interfuel substitution and to provide a comparison of our results with most of the existing empirical literature. In doing so, however, we use recent, state-of-the-art advances in microeconometrics to produce inference consistent with theoretical regularity — see, for example, Barnett and Serletis (2008) and Feng and Serletis (2008). In particular, motivated by the widespread practice of ignoring theoretical regularity, we use the normalized quadratic (NQ) cost function, introduced by Diewert and Wales (1987), estimate the corresponding input-output equations subject to the theoretical regularity conditions using methods developed by Diewert and Wales (1987), and produce inference consistent with neoclassical microeconomic theory.

Because the existing major contributions in this area are quite outdated, since their data incorporate few (if any) observations subsequent to the oil price shocks in the 1970s, we use the most recent data (since 1980), published by the International Energy Agency (IEA), for a number of OECD countries as well as for some non-OECD countries for which reliable data are available. In particular, we provide evidence for six high-income countries (Canada, France, Japan, Italy, the United Kingdom and the United States), for five upper-middle to high-income economies (Poland, Hungary, Mexico, Turkey and Venezuela), and for four lower-middle to low-income economies (China, India, South Africa and Thailand).

The rest of the paper is organized as follows. Section 2 briefly sketches the neoclassical energy problem. Section 3 discusses estimation issues while Section 4 discusses the data. Section 5 estimates the model using time series data for each country, assesses the results in terms of their consistency with optimizing behavior, and explores the economic significance of the results. In section 6, we provide a sectoral investigation, working with a number of countries and sectors for which data are available; data limitations make it impossible to deal with all sectors and for all countries. The final section concludes the paper with suggestions for potentially productive future research.

2 The NQ Cost Function

Most of the empirical energy demand literature has used the translog flexible functional form, due to Christensen *et al.* (1975). See, for example, Berndt and Wood (1975), Fuss (1977), Pindyck (1979), Uri (1979), Considine (1989), Hall (1986) and Jones (1995), among others. To demonstrate, consider the translog unit cost function, as recently used by Feng and Serletis (2008),

$$\ln C\left(\boldsymbol{p}, y, t\right) = \ln y + \beta_0 + \beta_t t + \sum_{i=1}^{n} \beta_i \ln p_i +$$

$$+ \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} \beta_{ij} \ln p_i \ln p_j + \sum_{i=1}^{n} \beta_{it} t \ln p_i + \frac{1}{2}\beta_{tt} t^2, \tag{1}$$

where $\beta_{ij} = \beta_{ji}$, t is a technology index, y denotes output and p_j is the price of the jth input. Homogeneity of degree one in prices (given y) implies the following restrictions

$$\sum_{i=1}^{n} \beta_i = 1, \;\; \sum_{i=1}^{n} \beta_{ij} = \sum_{j=1}^{n} \beta_{ji} = \sum_{i=1}^{n} \beta_{it} = 0. \tag{2}$$

Although one could estimate (1) directly, efficiency gains can be realized by estimating the optimal cost-minimizing input demand equations, transformed into cost-share equations, as follows

$$s_i = \frac{p_i x_i}{C} = \beta_i + \sum_{j=1}^{n} \beta_{ij} \ln p_j + \beta_{it} t, \tag{3}$$

where $\sum_{i=1}^{n} p_i x_i = C$.

Guilkey *et al.* (1983) show that the translog is globally regular if and only if technology is Cobb-Douglas. In other words, the translog performs well if substitution between all factors is close to unity. They also show that the regularity properties of the translog model deteriorate rapidly when substitution diverges from unity. More recently, Feng and Serletis (2008), in their investigation of productivity trends in U.S. manufacturing, report disappointing results with the translog specification, in terms of theoretical regularity violations, even when local curvature is imposed using methods suggested by Ryan and Wales (2000). This is consistent with earlier evidence by Serletis and Shahmoradi (2007), in the context of consumer theory, in their study of the demand for money and liquid assets in the United States.

In this paper, we started with the translog functional form with the objective of also providing a comparison of our results with those in most of the existing empirical energy demand literature. We followed Ryan and Wales (1998) and Moschini (1999) and, as in Feng and Serletis (2008), treated the curvature property as a maintained hypothesis and built it into the model, very much like the homogeneity in prices and symmetry properties of neoclassical production theory. The results, however, with the energy data used in this paper were disappointing, in terms of theoretical regularity violations and inferences about the own-price elasticities and the Allen own elasticities of substitution, invalidating the use of the translog model.

These problems with the translog specification led us to use a locally flexible functional form for which the theoretical curvature conditions can be imposed globally. This is the normalized quadratic (NQ) cost function, introduced by Diewert and Wales (1987). See Diewert and Wales (1987) and also Barnett and Serletis (2008) for more details regarding the NQ form.

The NQ cost function is given by

$$C\left(\boldsymbol{p}, y, t\right) = y\left[\sum_{i=1}^{n} \beta_i p_i + \frac{1}{2}\frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\beta_{ij}p_i p_j}{\sum_{i=1}^{N}\alpha_i p_i} + \sum_{i=1}^{n}\beta_{it}p_i t\right], \tag{4}$$

where we impose two restrictions on the $\boldsymbol{B} \equiv [\beta_{ij}]$ matrix

$$\beta_{ij} = \beta_{ji}, \qquad \text{for all } i, j; \tag{5}$$

$$\boldsymbol{B}\boldsymbol{p}^* = \boldsymbol{0}, \quad \text{for some } \boldsymbol{p}^* > \boldsymbol{0}. \tag{6}$$

Further, the α vector ($\alpha > \boldsymbol{0}$) is usually predetermined.

To obtain equations that are amenable to estimation, we apply Shephard's (1953) lemma,

$$x_i = \frac{\partial C\left(\boldsymbol{p}, y, t\right)}{\partial p_i}, \qquad i = 1, \cdots, n, \tag{7}$$

to equation (4), and by dividing through by y, we obtain the following input-output equations

$$\frac{x_i}{y} = \beta_i + \sum_{j=1}^{n}\beta_{ij}\frac{p_i}{\sum_{i=1}^{n}\alpha_i p_i} - \frac{1}{2}\alpha_i\left(\sum_{i=1}^{n}\sum_{j=1}^{n}\beta_{ij}\frac{p_i}{\sum_{i=1}^{n}\alpha_i p_i}\frac{p_j}{\sum_{j=1}^{n}\alpha_j p_j}\right) + \beta_{it}t. \tag{8}$$

Before estimating the system in (8), we express the main diagonal elements of the $\boldsymbol{B}$ matrix, β_{ii}, in terms of its off-diagonal elements by using equation (6) and assuming that $\boldsymbol{p}^* = \mathbf{1}_n$. Thus, by estimating the input-output equations (8), we obtain estimates of β_i, the technical change parameters β_{it}, and the off-diagonal elements of the $\boldsymbol{B}$ matrix, β_{ij} $(i \neq j)$. The main diagonal elements of the $\boldsymbol{B}$ matrix can be recovered from the restrictions imposed.

The Hessian matrix of the cost function (4) is obtained as follows

$$\nabla_{p_i p_j} C(\boldsymbol{p}, y, t) = \frac{\beta_{ij}}{\sum_{i=1}^n \alpha_i p_i} - \frac{\alpha_i \left(\sum_{j=1}^n \beta_{ij} p_j\right)}{\left(\sum_{i=1}^n \alpha_i p_i\right)^2}$$

$$- \frac{\alpha_i \left(\sum_{i=1}^n \beta_{ij} p_i\right)}{\left(\sum_{i=1}^n \alpha_i p_i\right)^2} + \frac{\alpha_i \alpha_j \left(\sum_{i=1}^n \sum_{j=1}^n p_i \beta_{ij} p_j\right)}{\left(\sum_{i=1}^n \alpha_i p_i\right)^3}. \tag{9}$$

Using the restrictions $\sum_{j=1}^n \beta_{ij} p_j^* = \mathbf{0}_n$ at the reference point, we have $\sum_{i=1}^n \sum_{j=1}^n p_i^* \beta_{ij} p_j^* = \sum_{i=1}^n \left(p_i^* \left(\sum_{j=1}^n \beta_{ij} p_j^*\right)\right) = 0$. Thus evaluating the above equation at $(\boldsymbol{p}^*, t^*)$ yields the following equation

$$\nabla_{p_i p_j} C(\boldsymbol{p}, y, t) = \frac{\beta_{ij}}{\left(\sum_{i=1}^n \alpha_i p_i^*\right)}. \tag{10}$$

Multiplying both sides of (10) by y and rearranging, we get $\nabla_{p_i p_j} C(\boldsymbol{p}, y, t) = \alpha' \ \boldsymbol{p}^{-1} \boldsymbol{B}$. Thus, the negative semidefiniteness of $\nabla_{p_i p_j} C(\boldsymbol{p}, y, t)$ at the reference point requires that $\boldsymbol{B}$ is negative semidefinite. More importantly, the negative semidefiniteness of $\boldsymbol{B}$ is not only the necessary condition for $\nabla_{p_i p_j} C(\boldsymbol{p}, y, t)$ to be concave locally at the reference point as we just showed, but it is also a sufficient condition for $\nabla_{p_i p_j} C(\boldsymbol{p}, y, t)$ to be concave globally (concave at every possible and imaginable point) — see Diewert and Wales (1987) for more details.

In practice, the concavity of $C(\boldsymbol{p}, y, t)$ may not be satisfied, in the sense that the estimated $\boldsymbol{B}$ matrix may not be negative semidefinite. In this case, to ensure global concavity (concavity at all possible prices) of the NQ cost function, we follow Diewert and Wales (1987) and Feng and Serletis (2008) and impose

$$\boldsymbol{B} = -\boldsymbol{K}\boldsymbol{K}', \tag{11}$$

where $\boldsymbol{K}$ is a lower triangular matrix which satisfies

$$\boldsymbol{K}' \boldsymbol{p}^* = \mathbf{0}_n. \tag{12}$$

Note that (12) and the lower triangular structure of $\boldsymbol{K}$ imply

$$\sum_{i=1}^n k_{ij} = 0, \qquad j = 1, \cdots, n. \tag{13}$$

As an example, for the case of three inputs (11) and (13) imply

$$\begin{aligned}
\beta_{11} &= -k_{11}^2 = -\left(k_{21} + k_{31}\right)^2; \\
\beta_{12} &= -k_{11}k_{21} = \left(k_{21} + k_{31}\right) k_{21}; \\
\beta_{13} &= -k_{11}k_{31} = \left(k_{21} + k_{31}\right) k_{31}; \\
\beta_{22} &= -\left(k_{21}^2 + k_{22}^2\right) = -k_{21}^2 - k_{32}^2; \\
\beta_{23} &= -\left(k_{21}k_{31} + k_{22}k_{32}\right) = -k_{21}k_{31} + k_{32}^2; \\
\beta_{33} &= -\left(k_{31}^2 + k_{32}^2 + k_{33}^2\right) = -\left(k_{31}^2 + k_{32}^2\right).
\end{aligned}$$

That is, we replace the elements of $\boldsymbol{B}$ in the input-output equations (8) by the elements of $\boldsymbol{K}$, thus ensuring global curvature. It should be noted that in the case of the NQ cost model, concavity is imposed globally rather than locally at the reference point as in the case of the translog specification. The main advantage of the NQ specification comes from its property that correct curvature conditions can be imposed globally without destroying the flexibility of the functional form.

3 Estimation of the NQ System

In order to estimate the equation system (8), a stochastic component, $\boldsymbol{\epsilon}_t$, is added to the set of input-output equations as follows

$$\boldsymbol{w}_t = \boldsymbol{\psi}\left(\boldsymbol{p}_t, t, \boldsymbol{\theta}\right) + \boldsymbol{\epsilon}_t, \tag{14}$$

where $\boldsymbol{w} = (w_1, \cdots, w_n)'$ is the vector of input-output ratios. $\boldsymbol{\epsilon}_t$ is a vector of stochastic errors and we assume that $\boldsymbol{\epsilon} \sim N\left(\mathbf{0}, \boldsymbol{\Omega}\right)$ where $\mathbf{0}$ is a null matrix and $\boldsymbol{\Omega}$ is the $n \times n$ symmetric positive definite error covariance matrix. $\boldsymbol{\psi}(\boldsymbol{p}_t, t, \boldsymbol{\theta}) = \left(\psi_1\left(\boldsymbol{p}_t, t, \boldsymbol{\theta}\right), \cdots, \psi_n\left(\boldsymbol{p}_t, t, \boldsymbol{\theta}\right)\right)'$, and $\psi_i\left(\boldsymbol{p}_t, t, \boldsymbol{\theta}\right)$ is given by the right-hand side of (8). In estimating the model, we proxy y in (8) by a Divisia quantity index, obtained by dividing total expenditure on all fuels by the corresponding Divisia price index.

One issue concerning our stochastic specification is that of endogeneity. At the individual firm level, it may be reasonably assumed that input prices on the right hand side of (14) are exogenous. At the more aggregated level, however, input prices are less likely to be exogenous. In this literature, the possibility of endogeneity has been addressed by using iterative three-stage least squares (3SLS), but the results generally have been about the same as those with iterative Zellner estimation — see, for example, Barnett *et al.* (1991). Diewert and Fox (2008) also argue that instrumental variables estimation may be more biased, since the instruments may not be completely exogenous, and Burnside (1996) shows that results can vary markedly depending on the set of instruments used.

We employ different elasticity measures to investigate the substitutability/complementarity relationship between fuels. The Allen-Uzawa elasicitity of substitution between fuels i and j, σ_{ij}^{a}, can be calculated as

$$\sigma_{ij}^{a} = \frac{CC_{ij}}{C_i C_j},$$

where C is the cost function in (4) and C_i and C_{ij} are the first and second partial derivatives of the cost function with respect to input prices, $C_i = \partial C/\partial p_i$ and $C_{ij} = \partial^2 C/\partial p_i \partial p_j$. See Uzawa (1964) and Diewert (1974) for more details. If $\sigma_{ij}^{a} > 0$ (that is, if increasing the jth price increases the optimal quantity of fuel i), we say that fuels i and j are Allen-Uzawa (net) substitutes. If $\sigma_{ij}^{a} < 0$, they are Allen-Uzawa (net) complements.

The own-price elasticities can be calculated as

$$\eta_{ij} = \frac{C_{ij} p_j}{C_i} = s_j \sigma_{ij}^{a},$$

where s_j is the cost share of fuel j. Finally, Blackorby and Russell (1989) show that the Morishima elasticity of substitution between fuels i and j, σ_{ij}^{m}, can be expressed as

$$\sigma_{ij}^{m} = \eta_{ij} - \eta_{jj}.$$

Notice that the Morishima elasticity looks at the impact on the ratio of two inputs, x_i/x_j. If $\sigma_{ij}^{m} > 0$ (that is, if increasing the j^{th} price increases the optimal quantity of fuel i relative to the optimal quantity of fuel j), we say that fuel j is a Morishima (net) substitute for fuel i. If $\sigma_{ij}^{m} < 0$, fuel j is a Morishima net complement to fuel i.

In this paper, the estimation is performed in TSP/GiveWin (version 4.5), using the FIML procedure, and the regularity conditions are checked as in Feng and Serletis (2008). That is, positivity is checked by checking if the estimated cost is positive, monotonicity is checked by direct computation of the values of the first gradient vector of the estimated cost function with respect to $\boldsymbol{p}$, and curvature is checked by examining the eigenvalues of the Hessian matrix provided that the monotonicity condition holds; curvature requires that these eigenvalues be negative or zero. See Feng and Serletis (2008) for more details.

4 Data

Energy consumption data are readily available for almost all countries, but fuel price data are available for only a small number of countries. Because of this data availability problem, we estimate models for those countries for which fuel quantity and price data are available for at least 15 years.

For the purpose of providing an international comparison, we use data for three groups of countries, in accordance with the most recent World Bank's country classification by income.

In particular, taking into consideration the fact that a large part of the empirical literature on interfuel substitution pertains to developed economies, our benchmark group consists of six high-income countries: Canada, France, Japan, Italy, the United Kingdom, and the United States; Germany is not included in this group, because of distortions in the quantity data following the unification of the country in the 1990s. The second group includes five upper-middle to high-income economies: Poland, Hungary, Mexico, Turkey, and Venezuela. The third group of countries includes four lower-middle to low-income economies: China, India, South Africa, and Thailand.

Individual fuel (total final) consumption data come from the *World Energy Statistics and Balances,* published by the International Energy Agency (IEA). All fuel quantities are expressed in kilotonnes of oil equivalent (ktoe). Individual fuel prices, in U.S. dollars per tonne of oil equivalent (toe), come from *Energy Prices and Taxes*, also published by the IEA. For consistency across the different countries, we use industrial sector prices as the representative fuel prices. Moreover, we use the high-sulphur fuel oil price as the representative price of oil and the steam coal price as the representative coal price. For those countries for which industrial sector prices are not available, we use different proxies; for example, we use the electricity-generation sector prices as a proxy for the coal price for South Africa and the industrial price of automotive diesel as a proxy for the oil price in Thailand.

Whenever possible, we use a four-input model, consisting of petroleum products ('oil'), natural gas, coal and electricity. For some countries, however, we use a three-input model, either because of the structure of the economy (i.e., Turkey did not use natural gas until the 1990s) or because of data availability issues. In particular, for Canada and Venezuela, we do not have data for the price of coal and therefore use a three-fuel model consisting of oil, natural gas and electricity. For China, India, Italy, South Africa, Thailand and Turkey we do not have data for natural gas prices and thus use a three-fuel model, consisting of oil, coal and electricity.

Finally, for the high-income countries (Canada, France, Japan, Italy, the United Kingdom and the United States) and Mexico, Hungary, Thailand and Turkey, the sample period is from 1980 to 2006, a total of 27 observations ($T = 27$). For India the sample period is from 1981 to 2005 ($T = 25$), for Venezuela from 1981 to 1999 ($T = 19$), for South Africa from 1980 to 2005 ($T = 26$), for Poland from 1986 to 2006 ($T = 21$) and for China from 1990 to 2006 ($T = 17$).

5 Interfuel Substitution at the National Level

Tables 1-15 contain a summary of results in terms of parameter estimates and positivity, monotonicity and curvature violations when the NQ model is estimated without the curvature conditions imposed (in the first column) and with the curvature conditions imposed (in the second column). Clearly, although positivity and monotonicity are satisfied at all sample observations, curvature is violated at all sample observations when the curvature conditions are not imposed (see the first column of Tables 1-15). Because regularity has not been attained, except for Venezuela, we follow the suggestions of Barnett (2002) and Barnett and Pasupathy (2003) and estimate the NQ model for each country by imposing curvature. In doing so, we impose global curvature, following the procedure suggested by Diewert and Wales (1987).

The results in the second column of Tables 1-15 are impressive, as they indicate that the imposition of global curvature (at all possible prices), reduces the number of curvature violations to zero, without any induced violations of monotonicity; only in the case of Thailand the imposition of curvature produces a monotonicity violation at one data point. Tables 1-15 also report the log likelihood values for both the unconstrained and constrained models. By comparing these log likelihood values, we see that the imposition of the curvature constraints has not much influence on the flexibility of the NQ model. In particular, the log likelihood values in most cases decrease only slightly. This means that the constrained NQ model can guarantee inference (including that about the own- and cross-price elasticities as well as the Allen and Morishima elasticities of substitution) consistent with theory, without compromising much of the flexibility of the functional form.

We start by reporting mean price elasticities in Tables 16, 17 and 18 for the six high-income countries (Canada, France, Japan, Italy, the United Kingdom and the United States), the five upper-middle to high-income countries (Poland, Hungary, Mexico, Turkey and Venezuela), and the four lower-middle to low-income countries (China, India, South Africa and Thailand), respectively. All elasticities reported in this paper are based on the formulas used by Feng and Serletis (2008). The own-price elasticities (η_{ii}) are all negative (as predicted by the theory), with the absolute values of these elasticities (in general) being less than 1, which indicates that the demands for all fuels are inelastic. Thailand presents the only exception with own-price elasticity for coal, η_{cc}, being -1.107; we will return to this interesting finding later. The negativeness of the own-price elasticities theoretically validates the use of the NQ model. For the cross-price elasticities (η_{ij}), economic theory does not predict any signs.

From the point of view of energy policy, the measurement of the elasticities of substitution among the different fuels is of prime importance. As already note in Section 3, there are currently two methods employed for calculating the partial elasticity of substitution between two variables, the Allen and Morishima. The Allen elasticity of substitution is the traditional measure and has been employed to measure substitution behavior and structural instability in a variety of contexts. However, when there are more than two inputs, the Allen elasticity may be uninformative — see, for example, Blackorby and Russell (1989). For two inputs the relationship is unambiguous: the inputs must be substitutes. When there are more than two inputs, the relationship becomes complex and depends on the direction taken toward the point of approximation. In that case the Morishima elasticity of substitution is the correct measure of substitution elasticity. The Morishima elasticity examines how changes in the price of input j (holding the price of input i fixed) affects the quantity ratio x_i/x_j. Inputs will be Morishima complements (substitutes) if an increase in the price of j causes x_i/x_j to decrease (increase).

Tables 19-21 show mean estimates of the Allen elasticities. We expect the diagonal terms, representing the Allen own-elasticities of substitution for the different fuels to be negative. This expectation is clearly achieved. Although the diagonal terms in Tables 19-21 are all negative, some of estimates reported in Tables 19-21 are large (in absolute terms). This is, for example, the case of electricity in the United Kingdom and the United States (see Table 19) and Hungary and Mexico (see Table 20) and also the case of coal in South Africa and Thailand (see Table 21). This can be explained by writing σ_{ij}^a as $\sigma_{ij}^a = \eta_{ij}/s_j$, indicating that σ_{ij}^a is large when the cost share s_j is small. However, because the Allen elasticity of substitution produces ambiguous results off-diagonal, we use the Morishima elasticity of substitution to investigate the substitutability/complementarity relation between fuels. The asymmetrical Morishima elasticities of substitution — the correct measures of substitution — as documented in Tables 22-24 (mean Morishima elasticities are reported), are in general less than unity, with only σ_{ec}^m for the United Kingdom and Thailand and σ_{oc}^m, σ_{co}^m and σ_{ce}^m for Thailand being greater than 1 in absolute terms. Moreover, most of the Morishima elasticities of substitution are positive (although small), suggesting substitutability among the different fuels.

Let us consider the Morishima elasticity of substitution between oil (o) and natural gas (g), σ_{og}^m, which represents the percentage change in the o/g ratio when the relative price p_g/p_o is changed by changing p_g and holding p_o constant. As can be seen in Tables 22-24, σ_{og}^m and σ_{go}^m are both positive, except for France, Japan and Poland, suggesting that oil and natural gas are in general Morishima substitutes, irrespective of whether the price of oil or the price of natural gas changes. Similarly, oil and coal are Morishima substitutes (irrespective of whether the price of oil or the price of coal changes), except for Mexico, Italy, China and India. Oil and electricity are Morishima substitutes, except for Canada, the United Kingdom, Poland and Hungary. Finally, natural gas and coal are Morishima substitutes for all countries, except for the United States, Hungary and South Africa, and natural gas and electricity are Morishima substitutes, except for the United Kingdom and South Africa.

Regarding the Morishima elasticities of substitution, we see that in the case of the high-income countries, only the United Kingdom and the United States show some mild substitutability between electricity and other fuels when the price of electricity is changing. There is also strong evidence of substitutability between electricity and coal in response to changes in the price of coal ($\sigma_{ec}^m = 1.242$) in the United Kingdom. In the case of the upper-middle to high-income countries, only Hungary shows mild substitutability between electricity and other fuels, regardless of which fuel price is changing (see Table 23). Finally, in the case of the lower-middle to low-income countries, there is some mild substitution between coal and oil ($\sigma_{co}^{m} = .757$) as well as between electricity and oil ($\sigma_{eo}^{m} = .427$) in South Africa, when the price of oil is changing, but not otherwise. Thailand shows the highest potential of substitution, with coal being highly substitutable with any other fuel, regardless of which direction the price change comes from. This also explains the highly elastic demand for coal in Thailand, mentioned earlier. This phenomenon of an elastic demand for coal and high substitutability between coal and the other fuels in Thailand can be explained by the structure of that economy; in particular, more than 80% of coal is used in the electricity generation sector and is readily replaceable with natural gas and other fuels.

The results outlined above have a number of implications for policymakers and government agencies responsible for natural resources management and energy regulation. First, the possibility of interfuel substitution at the national level seems to be very limited for the majority of the countries under investigation, with few exceptions. Therefore, it is highly unlikely that government programs implying such a possibility (such as switching from "dirty" to "clean" fuels to reduce the amount of carbon dioxide emissions) will deliver any substantial results in the near future. Second, for those economies that do exhibit some potential of substitution between energy inputs, there exists a distinct pattern of substitution between fossil fuels and electricity — as in the case of the United Kingdom, the United States, Hungary, and South Africa. For this reason, policymakers in these countries should base their energy programs not on substitution between fossil fuels (such as crude oil, natural gas, and coal), but between either of the fossil fuels and electricity.

Finally, our findings suggest that the potential of aggregate interfuel substitution does not depend on the level of economic development of any particular country, but rather is a function of the specific structure of the national economy. Therefore, any collegial decisions regarding economic development (such as, for example, in the G7 format) are likely to be less effective than those taking into account the structural characteristics of the national economies.

6 Sectoral Interfuel Substitution

We have investigated interfuel substitution for entire economies using time series data for each economy. The structure of interfuel substitution, however, is different for different sectors of use. In this section we provide a sectoral investigation, working with a number of countries and sectors for which data are available. Data limitations make it impossible to deal with all sectors and for all countries. We also use different proxies (mentioned in what follows) to overcome data scarcity problems.

For the purpose of our sectoral analysis, we calculate the aggregate quantities of individual fuels for the industrial, residential, electiricity generation, and transporation sectors, using *Extended Energy Balances* series from the IEA. For the sectoral models, we do not report parameter estimates, own- and cross-price elasticities, and Allen elasticities of substitution;

these are available upon request. Our results indicate that, as in the aggregate data, most of the sectoral elasticities of substitution are positive, suggesting substitutability among the different fuels. They are, however, generally very low, revealing the limited ability in changing the fuel mix across sectors and countries.

6.1 Industrial Sector

Because of data limitations, we estimated a number of four- and three-fuel models for the industrial sectors of the countries shown in the following table

Industrial sector models

4-fuels, (o, g, e, c)	3-fuels, (o, g, e)	3-fuels, (o, c, e)
France	Canada	Italy
Japan	Hungary	South Africa
Poland	Mexico	Thailand
United Kingdom	Venezuela	Turkey
United States		

The sample period is from 1980 to 2006 for all countries ($T = 27$), except for Poland (1986-2006; $T = 21$), Hungary (1985-2006; $T = 22$), Venezuela (1981-1999; $T = 19$), and South Africa (1990-2005; $T = 16$). With the industrial sector models, we use the high sulphur fuel oil price as the representative price of oil and the steam coal price as the representative price of coal.

Let's consider the industrial Morishima elasticities of substitution in Tables 25-27. In general, they are less than unity, with only σ^m_{og}, σ^m_{cg} and σ^m_{eg} for Japan, σ^m_{eo} for Italy, σ^m_{cg} for the United Kingdom and σ^m_{oc}, σ^m_{co} and σ^m_{ec} for Thailand being greater than 1 in absolute terms. They indicate strong substitutability between natural gas and other fuels in Japan, when the price of natural gas is changing, and mild substitutability when the prices of the other fuels are changing. They also indicate strong substitutability between oil and electricity in Italy's industrial sector (irrespective of whether the price of oil or the price of electricity changes), strong substitutability between natural gas and coal in the United Kingdom (irrespective of whether the price of gas or coal changes) and mild substitutability between coal and other fuels in the industrial sector of the United States when the price of coal is changing, but the relation does not always hold otherwise. Regarding the industrial sectors of the upper-middle to high-income countries and the lower-middle to low-income countries, only Poland shows mild substitution between oil and natural gas.

The evidence on interfuel substitution in the industrial sectors of the countries under investigation presents one interesting finding. Unlike the case with the national level data, on average, countries with a higher level of economic development seem to exhibit higher potential of substitution between different fuel types than the developing economies. Therefore, our earlier conclusion regarding collegial decisions on interfuel substitution does not apply in this case.

6.2 Residential Sector

We also estimated a number of four- and three-fuel models for the residential sectors of the countries shown in the following table

Residential sector models

4-fuels, (o, g, e, c)	3-fuels, (o, g, e)	3-fuels, (o, c, e)	3-fuels, (g, c, e)
United Kingdom	Canada	South Africa	Poland
Hungary	France	Turkey	
	Japan		
	Venezuela		
	United States		

Again, the sample period for the residential sector models is from 1980 to 2006 for all countries ($T = 27$), except for Venezuela (1981-1999; $T = 19$), Poland (1986-2006; $T = 21$) and South Africa (1990-2005; $T = 16$). With the residential sector models, we use the light fuel oil price as the representative oil price, and, as in the industrial sector, we use the steam coal price as the representative coal price.

As with the industrial Morishima elasticities of substitution, the residential ones, reported in Tables 28-30, are also generally less than unity. In particular, there is strong substitutability between electricity and gas in the residential sector of Japan (irrespective of whether the price of gas or the price of electricity changes), mild substitutability between coal and electricity in Poland and Hungary (irrespective of which price changes), mild substitutability between oil and electricity in Turkey and mild substitutability between coal and oil in South Africa.

Our evidence on interfuel substitution in the residential sector fails to detect any distinctive pattern regarding either the substitution between any particular fuels (as in the case of the national level data) or the relationship between interfuel substitution and the level of economic development (as in the case of the industrial sector analysis). This finding is quite expected. Keeping in mind that the energy inputs in the residential sector are used primarily for heating, it seems natural that interfuel substitution in that sector is only a function of country's economic structure, its geographical location, and the available natural resources.

6.3 Electricity Generation Sector

For the electricity generation sector we are estimating only three-fuel (o, g, c) models for the five countries shown in the following table

Electricity-generation sector models
3-fuels, (o, g, c)
Japan
United Kingdom
United States
Mexico
Turkey

The sample period for the electricity-generation sector models is from 1980 to 2006 for the United States, the United Kingdom, and Mexico ($T = 27$), from 1980 to 1997 for Japan ($T = 18$), and from 1988 to 2006 for Turkey ($T = 19$). The results are presented in Tables 31-32.

The Morishima elasticities of substitution in the electricity generation sector are also less than unity. Only σ^m_{og}, σ^m_{go} and σ^m_{co} for the United States are greater than 1 in absolute terms, suggesting that oil and natural gas are Morishima substitutes (irrespective of whether the price of oil or the price of gas changes) and that coal and oil are also substitutes when the price of oil changes, but not when the price of coal changes. There is also evidence of mild substitutability in Turkey, between oil and gas (irrespective of which price changes) and also between coal and oil when the price of oil changes.

The evidence regarding interfuel substitution in the electricity generation sector is similar to that for the residential sector, revealing no distinct patterns as to particular fuels or country groups. However, the number of countries used to investigate interfuel substitution in the electricity generation sector is too limited to reach any conclusions regarding its relevance in the government decision-making process. Only in the case of the United States we find convincing evidence of substitutability among fossil fuels, suggesting that efforts by U.S. policymakers to substitute coal with more environmentally friendly sources of energy seem to have a very solid ground.

6.4 Transportation Sector

Finally, we are estimating a number of four- and three-fuel models for the following fuels (note the different notation in this subsection): fuel oil (o), diesel (d), gasoline (s), and electricity (e). In doing so, because of data limitations, we use the automotive diesel and light fuel oil prices in the industrial sector to proxy the price of diesel and fuel oil, respectively, in the transportation sector. Whenever the light fuel oil price is not available (as in the case of

Turkey), we use the industrial high sulphur fuel oil price as the price of fuel oil. We also use the premium leaded gasoline and electricity prices from the household sector to proxy the price of gasoline and electricity, respectively, in the transportation sector. In those cases that the premium leaded gasoline price is missing (as, for example, in the case of Canada, Japan, Mexico, and the United States), we use the regular unleaded gasoline price as the price of gasoline.

Taking into account the specifics of each economy and data limitations, we restrict our analysis to the countries and models shown in the following table

Transportation sector models

4-fuels, (o, d, s, e)	3-fuels, (d, s, e)	3-fuels, (o, s, d)
Canada	France	Indonesia
Japan	Italy	
Turkey	Mexico	
United Kingdom	South Africa	
United States		

The sample period for the transportation sector models is from 1980 to 2006 for Canada, France, Japan, Italy, Mexico, South Africa, Turkey, and the United States ($T = 27$) and from 1980 to 2004 for the United Kingdom and Indonesia ($T = 25$).

The transportation Morishima elasticities of substitution are reported in Tables 33-35. These elasticities of substitution are also in general less than unity, for most countries, except for the United States. For the United States, there is evidence of strong substitution between fuel oil and gasoline (irrespective of whether the price of fuel oil or the price of gasoline changes), as $\sigma^m_{os} = 26.617$ and $\sigma^m_{so} = 3.996$. There is evidence of substitutability between fuel oil and electricity when the price of fuel oil changes ($\sigma^m_{eo} = 3.851$) and complementarity when the price of electricity changes ($\sigma^m_{oe} = -2.757$). There is also evidence of strong substitution between fuel oil and diesel when the price of fuel oil changes ($\sigma^m_{do} = 3.984$) and evidence of strong complementarity between fuel oil and diesel when the price of diesel changes ($\sigma^m_{od} = -19.692$).

The results for the transportation sector are very similar to those for the industrial sector. On average, rich countries exhibit higher potential of substitution among energy goods than poor countries. In practical terms, and from a policy perspective, programs designed to switch to “greener” fuels will be most feasible in countries like Canada, Japan, the United Kingdom, and the United States.

7 Conclusion

We have investigated interfuel substitution, taking a flexible functional form approach and using state-of-the-art recent advances in microeconometrics. In particular, to minimize the potential problem of using a misspecified functional form, we have employed a well-known flexible functional form, the locally flexible normalized quadratic (NQ), introduced by Diewert and Wales (1987). Moreover, motivated by the widespread practice of ignoring the theoretical regularity conditions, we have estimated the model subject to theoretical regularity using methods developed by Diewert and Wales (1987). We have produced inference about the demand for fuels, including those about the own- and cross-price elasticities as well as the Allen and Morishima elasticities of substitution, that is consistent with neoclassical microeconomic theory.

Our evidence indicates that the interfuel elasticities of substitution are (in general) consistently below unity, revealing the limited ability to substitute one source of energy with another and suggesting that fossil fuels will continue to maintain their major role as a source of energy in the near future. At the national level, we find a consistent pattern of substitutability between electricity and fossil fuels for a number of countries under investigation. Therefore, policymakers in these countries should base their programs on this particular type of interfuel substitution, and not those involving the substitution of one fossil fuel with another. We also find very little evidence of interfuel substitution using sectoral data. Only in the U.S. transportation sector we find evidence of strong substitutability among some of the fuels. On average, developed countries exhibit higher potential of substitution between energy inputs in their industrial and transportation sectors than developing economies. Hence, policymakers' efforts are more likely to deliver expected results if they are focused on a particular sector of the economy rather than on the aggregate economy.

Although we find some evidence that the high-income economies have larger potential of interfuel substitution in their industrial and transportation sectors, our results do not suggest any significant differences between the three groups of countries in terms of interfuel substitution in the residential and electricity generation sectors or at the national level. That is, interfuel substitution seems to depend on the structure of the economy, but to be independent of the level of economic development. In this respect, the effectiveness of policymakers' collegial decisions as to the substitution of one energy input with another will depend on the target sector of the economy. According to our findings, energy policy will be more effective in targeting substitution in the industrial and transportation sectors than in the residential and electricity generation sectors.

Overall, our results highlight the fact that the substitution between different energy inputs has been quite restricted. Therefore, such daunting tasks as curbing carbon emissions and preventing climate change require a more active and focused energy policy. Also, because interfuel substitution is limited in the near term, there will be a greater need for relative price changes to induce switching to a lower carbon economy.

Finally, it should be mentioned that although the present paper presents international evidence on interfuel substitution consistent with the theoretical regularity conditions of neoclassical microeconomic theory, in doing so, it uses a locally flexible functional form, as most of the existing empirical energy demand literature does. Locally flexible functional forms provide the capability to approximate systems resulting from a broad class of generating functions and also to attain arbitrary elasticities of substitution — although at only one point (that is, locally). An innovation in this respect is the use of semi-nonparametric flexible functional forms that possess global flexibility and in which asymptotic inferences are potentially free from any specification error. Semi-nonparametric functions can provide an asymptotically global approximation to complex economic relationships. These functions provide global approximations to the true data generating process and its partial derivatives. By global approximation, we mean that the flexible functional form is capable, in the limit, of approximating the unknown underlying generating function at all points and thus of producing arbitrarily accurate elasticities at all data points. Two such semi-nonparametric functions are the Fourier flexible functional form, introduced by Gallant (1981), and the Asymptotically Ideal Model (AIM), employed and explained in Barnett and Yue (1988). These models have been recently employed by Serletis and Shahmoradi (2008) in the context of interfuel substitution in U.S. energy demand. Although these semi-nonparametric functions are parameter intensive, their use in the investigation of interfuel substitution and energy demand is a potentially productive area for future research.

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TABLE 1

NQ PARAMETER ESTIMATES FOR CANADA

Inputs:

1 = oil
2 = electricity
3 = natural gas

Parameter	Unrestricted	Global curvature imposed
β_1	.4256 (.000)	.4229 (.000)
β_2	.4087 (.000)	.4103 (.000)
β_3	.1724 (.000)	.1726 (.000)
β_{12}	$-$.0174 (.001)	$-$.0048 (.001)
β_{13}	.0180 (.001)	.0208 (.001)
β_{23}	.0075 (.015)	.0063 (.022)
β_{1t}	$-$.0014 (.008)	$-$.0014 (.001)
β_{2t}	.0016 (.001)	.0016 (.000)
β_{3t}	.0001 (.231)	.0001 (.148)
Log$L$	301.575	298.689
Positivity violations	0	0
Monotonicity violations	0	0
Curvature violations	27	0

Note: Sample period, annual data 1980-2006 ($T = 27$).

Table 2

NQ Parameter Estimates For France

Inputs:

1 = oil
2 = natural gas
3 = coal
4 = electricity

Parameter	Unrestricted	Global curvature imposed
β_1	.5010 (.000)	.4980 (.000)
β_2	.3508 (.000)	.3531 (.000)
β_3	.1336 (.000)	.1335 (.000)
β_4	.0264 (.000)	.0268 (.000)
β_{12}	−.0177 (.000)	−.0012 (.568)
β_{13}	.0108 (.256)	.0104 (.140)
β_{14}	.0014 (.382)	.0009 (.381)
β_{23}	.0022 (.569)	.0012 (.628)
β_{24}	−.0024 (.001)	.0001 (.475)
β_{34}	−.0013 (.523)	−.0009 (.308)
β_{1t}	−.0054 (.000)	−.0053 (.000)
β_{2t}	.0047 (.000)	.0047 (.000)
β_{3t}	.0010 (.000)	.0009 (.000)
β_{4t}	−.0007 (.000)	−.0007 (.000)
Log$L$	481.021	464.366
Positivity violations	0	0
Monotonicity violations	0	0
Curvature violations	27	0

Note: Sample period, annual data 1980-2006 ($T = 27$).

TABLE 3

NQ PARAMETER ESTIMATES FOR JAPAN

Inputs:

1 = oil
2 = natural gas
3 = coal
4 = electricity

Parameter	Unrestricted	Global curvature imposed
β_1	.4480 (.000)	.4446 (.000)
β_2	.4780 (.000)	.4804 (.000)
β_3	.0517 (.000)	.0516 (.000)
β_4	.0251 (.000)	.0254 (.000)
β_{12}	−.0010 (.693)	−.0003 (.835)
β_{13}	.0086 (.016)	.0163 (.000)
β_{14}	−.0009 (.807)	.0019 (.338)
β_{23}	−.0108 (.000)	.0003 (.837)
β_{24}	−.0019 (.370)	.0000 (.843)
β_{34}	−.0010 (.746)	−.0018 (.297)
β_{1t}	−.0035 (.000)	−.0034 (.000)
β_{2t}	.0010 (.000)	.0012 (.000)
β_{3t}	.0013 (.000)	.0011 (.000)
β_{4t}	−.0001 (.057)	−.0002 (.000)
Log$L$	514.348	505.482
Positivity violations	0	0
Monotonicity violations	0	0
Curvature violations	27	0

Note: Sample period, annual data 1980-2006 ($T = 27$).

TABLE 4

NQ PARAMETER ESTIMATES FOR ITALY

Inputs:

1 = oil
2 = electricity
3 = coal

Parameter	Unrestricted	Global curvature imposed
β_1	.6842 (.000)	.6842 (.000)
β_2	.2990 (.000)	.2988 (.000)
β_3	.0093 (.000)	.0095 (.000)
β_{12}	.0287 (.000)	.0233 (.000)
β_{13}	$-$.0057 (.005)	$-$.0020 (.026)
β_{23}	.0006 (.861)	.0022 (.039)
β_{1t}	$-$.0045 (.074)	$-$.0045 (.074)
β_{2t}	.0060 (.000)	.0060 (.000)
β_{3t}	$-$.0001 (.010)	$-$.0001 (.000)
Log$L$	386.189	384.920
Positivity violations	0	0
Monotonicity violations	0	0
Curvature violations	27	0

Note: Sample period, annual data 1980-2006 ($T = 27$).

TABLE 5

NQ PARAMETER ESTIMATES FOR U.K.

Inputs:

1 = oil
2 = natural gas
3 = coal
4 = electricity

Parameter	Unrestricted	Global curvature imposed
β_1	.4709 (.000)	.4702 (.000)
β_2	.3266 (.000)	.3259 (.000)
β_3	.1582 (.000)	.1587 (.000)
β_4	.0473 (.000)	.0482 (.000)
β_{12}	.0103 (.001)	.0081 (.029)
β_{13}	.0126 (.016)	.0148 (.000)
β_{14}	$-$.0077 (.006)	$-$.0054 (.034)
β_{23}	$-$.0029 (.313)	$-$.0022 (.450)
β_{24}	$-$.0046 (.113)	$-$.0006 (.721)
β_{34}	.0153 (.000)	.0157 (.000)
β_{1t}	$-$.0008 (.000)	$-$.0008 (.000)
β_{2t}	.0019 (.000)	.0019 (.000)
β_{3t}	.0003 (.001)	.0003 (.000)
β_{4t}	$-$.0017 (.000)	$-$.0018 (.000)
Log$L$	483.492	482.359
Positivity violations	0	0
Monotonicity violations	0	0
Curvature violations	27	0

Note: Sample period, annual data 1980-2006 ($T = 27$).

Table 6

NQ Parameter Estimates For U.S.

Inputs:

1 = oil
2 = natural gas
3 = coal
4 = electricity

Parameter	Unrestricted	Global curvature imposed
β_1	.4582 (.000)	.4540 (.000)
β_2	.3554 (.000)	.3628 (.000)
β_3	.1710 (.000)	.1672 (.000)
β_4	.0173 (.000)	.0173 (.000)
β_{12}	−.0095 (.021)	.0007 (.722)
β_{13}	.0081 (.013)	.0037 (.242)
β_{14}	−.0004 (.848)	.0013 (.393)
β_{23}	−.0141 (.000)	−.0014 (.279)
β_{24}	−.0003 (.938)	.0015 (.413)
β_{34}	.0024 (.259)	.0100 (.002)
β_{1t}	−.0025 (.000)	−.0023 (.000)
β_{2t}	.0041 (.000)	.0037 (.000)
β_{3t}	−.0019 (.391)	−.0017 (.000)
β_{4t}	−.0005 (.000)	−.0005 (.000)
Log$L$	479.170	469.575
Positivity violations	0	0
Monotonicity violations	0	0
Curvature violations	27	0

Note: Sample period, annual data 1980-2006 ($T = 27$).

Table 7

NQ Parameter Estimates For Poland

Inputs:

1 = oil
2 = natural gas
3 = coal
4 = electricity

Parameter	Unrestricted	Global curvature imposed
β_1	.2718 (.000)	.2668 (.000)
β_2	.3419 (.000)	.3529 (.000)
β_3	.1862 (.000)	.1875 (.000)
β_4	.1648 (.000)	.1535 (.000)
β_{12}	−.0227 (.008)	−.0091 (.117)
β_{13}	.0419 (.000)	.0413 (.000)
β_{14}	.0102 (.206)	−.0008 (.833)
β_{23}	.0214 (.013)	.0122 (.210)
β_{24}	−.0376 (.000)	−.0003 (.807)
β_{34}	−.0040 (.443)	.0012 (.824)
β_{1t}	.0104 (.000)	.0106 (.000)
β_{2t}	.0005 (.087)	.0001 (.685)
β_{3t}	.0010 (.001)	.0010 (.001)
β_{4t}	−.0054 (.000)	−.0050 (.000)
Log$L$	290.957	283.120
Positivity violations	0	0
Monotonicity violations	0	0
Curvature violations	21	0

Note: Sample period, annual data 1980-2006 ($T = 21$).

Table 8

NQ Parameter Estimates For Hungary

Inputs:

1 = oil
2 = natural gas
3 = coal
4 = electricity

Parameter	Unrestricted	Global curvature imposed
β_1	.5588 (.000)	.5600 (.000)
β_2	.2509 (.000)	.2445 (.000)
β_3	.1286 (.000)	.1281 (.000)
β_4	.0538 (.000)	.0580 (.000)
β_{12}	.0205 (.070)	.0297 (.003)
β_{13}	.0272 (.007)	.0367 (.000)
β_{14}	$-$.0171 (.000)	$-$.0193 (.000)
β_{23}	$-$.0139 (.022)	$-$.0171 (.002)
β_{24}	$-$.0019 (.801)	.0099 (.004)
β_{34}	.0184 (.000)	.0185 (.000)
β_{1t}	$-$.0034 (.000)	$-$.0032 (.000)
β_{2t}	.0036 (.000)	.0035 (.000)
β_{3t}	.0040 (.000)	.0038 (.000)
β_{4t}	$-$.0015 (.000)	$-$.0015 (.000)
Log$L$	398.636	396.032
Positivity violations	0	0
Monotonicity violations	0	0
Curvature violations	27	0

Note: Sample period, annual data 1980-2006 ($T = 27$).

Table 9

NQ Parameter Estimates For Mexico

Inputs:

1 = oil
2 = natural gas
3 = coal
4 = electricity

Parameter	Unrestricted	Global curvature imposed
β_1	.2385 (.000)	.2367 (.000)
β_2	.5961 (.000)	.5957 (.000)
β_3	.1000 (.000)	.1012 (.000)
β_4	.0300 (.000)	.0303 (.000)
β_{12}	.0076 (.066)	.0049 (.014)
β_{13}	$-$.0034 (.137)	$-$.0029 (.000)
β_{14}	.0003 (.826)	.0016 (.069)
β_{23}	.0049 (.020)	.0064 (.000)
β_{24}	.0029 (.255)	.0024 (.360)
β_{34}	.0011 (.321)	.0001 (.793)
β_{1t}	$-$.0015 (.000)	$-$.0016 (.000)
β_{2t}	.0139 (.000)	.0140 (.000)
β_{3t}	$-$.0015 (.000)	$-$.0015 (.000)
β_{4t}	$-$.0009 (.000)	$-$.0009 (.000)
Log$L$	437.159	436.537
Positivity violations	0	0
Monotonicity violations	0	0
Curvature violations	27	0

Note: Sample period, annual data 1980-2006 ($T = 27$).

TABLE 10

NQ PARAMETER ESTIMATES FOR TURKEY

Inputs:

1 = oil
2 = electricity
3 = coal

Parameter	Unrestricted	Global curvature imposed
β_1	.6785 (.000)	.6789 (.000)
β_2	.2264 (.000)	.2269 (.000)
β_3	.1219 (.000)	.1209 (.000)
β_{12}	.0183 (.001)	.0160 (.000)
β_{13}	.0231 (.015)	.0254 (.001)
β_{23}	$-$.0158 (.073)	$-$.0098 (.000)
β_{1t}	$-$.0104 (.000)	$-$.0103 (.000)
β_{2t}	.0075 (.000)	.0076 (.000)
β_{3t}	$-$.0017 (.000)	$-$.0019 (.000)
Log$L$	282.927	282.694
Positivity violations	0	0
Monotonicity violations	0	0
Curvature violations	27	0

Note: Sample period, annual data 1980-2006 ($T = 27$).

TABLE 11

NQ PARAMETER ESTIMATES FOR VENEZUELA

Inputs:

1 = oil
2 = electricity
3 = natural gas

Parameter	Unrestricted	Global curvature imposed
β_1	.0887 (.000)	
β_2	.5766 (.000)	
β_3	.3198 (.000)	
β_{12}	$-$.0005 (.650)	
β_{13}	.0021 (.068)	
β_{23}	.0383 (.000)	
β_{1t}	$-$.0011 (.000)	
β_{2t}	.0047 (.000)	
β_{3t}	$-$.0031 (.025)	
Log$L$	221.522	
Positivity violations	0	
Monotonicity violations	0	
Curvature violations	0	

Note: Sample period, annual data 1980-2006 ($T = 19$).

TABLE 12

NQ PARAMETER ESTIMATES FOR CHINA

Inputs:

1 = oil
2 = electricity
3 = coal

Parameter	Unrestricted	Global curvature imposed
β_1	.1730 (.000)	.1757 (.000)
β_2	.0787 (.000)	.0792 (.000)
β_3	.7500 (.000)	.7465 (.000)
β_{12}	.0132 (.284)	.0070 (.514)
β_{13}	−.0511 (.075)	−.0056 (.442)
β_{23}	.0172 (.492)	.0289 (.214)
β_{1t}	.0114 (.000)	.0113 (.000)
β_{2t}	.0081 (.000)	.0081 (.000)
β_{3t}	−.0202 (.000)	−.0200 (.000)
Log$L$	191.251	189.986
Positivity violations	0	0
Monotonicity violations	0	0
Curvature violations	17	0

Note: Sample period, annual data 1980-2006 ($T = 17$).

TABLE 13

NQ PARAMETER ESTIMATES FOR INDIA

Inputs:

1 = oil
2 = electricity
3 = coal

Parameter	Unrestricted	Global curvature imposed
β_1	.9540 (.000)	.9683 (.000)
β_2	.0837 (.000)	.0863 (.000)
β_3	.0245 (.000)	.0259 (.000)
β_{12}	$-$.0202 (.000)	.0003 (.691)
β_{13}	$-$.0054 (.000)	$-$.0002 (.583)
β_{23}	.0049 (.000)	.0013 (.004)
β_{1t}	$-$.0120 (.000)	$-$.0198 (.000)
β_{2t}	.0012 (.003)	.0032 (.003)
β_{3t}	.0008 (.000)	.0011 (.000)
Log$L$	297.103	281.868
Positivity violations	0	0
Monotonicity violations	0	0
Curvature violations	25	0

Note: Sample period, annual data 1980-2006 ($T = 25$).

Table 14

NQ Parameter Estimates For South Africa

Inputs:

1 = oil
2 = natural gas
3 = coal
4 = electricity

Parameter	Unrestricted	Global curvature imposed
β_1	.7631 (.000)	.7613 (.000)
β_2	.1987 (.000)	.2014 (.000)
β_3	.0057 (.000)	.0052 (.000)
β_4	.0327 (.000)	.0323 (.000)
β_{12}	.0136 (.003)	.0143 (.000)
β_{13}	.0037 (.001)	.0036 (.001)
β_{14}	.0022 (.338)	.0072 (.000)
β_{23}	$-$.0025 (.005)	$-$.0020 (.000)
β_{24}	$-$.0130 (.000)	$-$.0041 (.000)
β_{34}	$-$.0014 (.138)	$-$.0010 (.005)
β_{1t}	$-$.0021 (.000)	$-$.0021 (.000)
β_{2t}	.0020 (.000)	.0019 (.000)
β_{3t}	.0000 (.093)	.0001 (.000)
β_{4t}	$-$.0005 (.000)	$-$.0005 (.000)
Log$L$	517.776	509.496
Positivity violations	0	0
Monotonicity violations	0	0
Curvature violations	26	0

Note: Sample period, annual data 1980-2006 ($T = 26$).

Table 15

NQ Parameter Estimates For Thailand

Inputs:

1 = oil
2 = electricity
3 = coal

Parameter	Unrestricted	Global curvature imposed
β_1	.7819 (.000)	.7803 (.000)
β_2	.2086 (.000)	.2101 (.000)
β_3	.0047 (.256)	.0042 (.206)
β_{12}	.0488 (.000)	.0501 (.000)
β_{13}	.1066 (.005)	.1033 (.005)
β_{23}	$-$.0320 (.000)	$-$.0306 (.000)
β_{1t}	$-$.0035 (.000)	$-$.0035 (.000)
β_{2t}	.0030 (.000)	.0030 (.000)
β_{3t}	$-$.0006 (.206)	$-$.0005 (.098)
Log$L$	333.560	333.515
Positivity violations	0	0
Monotonicity violations	0	1
Curvature violations	27	0

Note: Sample period, annual data 1980-2006 ($T = 27$).

Table 16

Own- And Cross-Price Elasticities For High-Income Countries

Country	Factor i	Own- and cross-price elasticities			
		η_{io}	η_{ig}	η_{ic}	η_{ie}
Canada					
	o	$-.036$	$.050$	–	$-.013$
	g	$.108$	$-.147$	–	$.039$
	c	–	–	–	–
	e	$-.010$	$.015$	–	$-.004$
France					
	o	$-.025$	$-.005$	$.028$	$.002$
	g	$-.004$	$-.001$	$.005$	$.000$
	c	$.069$	$.014$	$-.077$	$-.006$
	e	$.077$	$.015$	$-.085$	$-.007$
Japan					
	o	$-.034$	$-.004$	$.035$	$.003$
	g	$-.001$	$-.000$	$.002$	$.000$
	c	$.187$	$.026$	$-.192$	$-.021$
	e	$.067$	$.008$	$-.068$	$-.007$
Italy					
	o	$-.029$	–	$-.001$	$.031$
	g	–	–	–	–
	c	$-.293$	–	$-.018$	$.311$
	e	$.062$	–	$.004$	$-.066$
U.K.					
	o	$-.040$	$.017$	$.035$	$-.012$
	g	$.018$	$-.013$	$-.002$	$-.003$
	c	$.088$	$-.005$	$-.175$	$.092$
	e	$-.416$	$-.094$	1.067	$-.556$
U.S.					
	o	$-.014$	$.000$	$.012$	$.002$
	g	$.000$	$-.001$	$-.001$	$.002$
	c	$.024$	$-.004$	$-.028$	$.007$
	e	$.084$	$.138$	$.177$	$-.400$

TABLE 17

OWN- AND CROSS-PRICE ELASTICITIES FOR UPPER-MIDDLE TO HIGH-INCOME COUNTRIES

Country	Factor i	Own- and cross-price elasticities η_{io}	η_{ig}	η_{ic}	η_{ie}
Poland					
	o	−.058	−.037	.099	−.004
	g	−.018	−.012	.033	−.001
	c	.137	.092	−.241	.010
	e	−.007	−.006	.015	−.001
Hungary					
	o	−.069	.047	.058	−.036
	g	.103	−.081	−.068	.045
	c	.189	−.101	−.209	.121
	e	−.786	.542	.777	−.533
Mexico					
	o	−.009	.012	−.008	.005
	g	.009	−.045	.034	.001
	c	−.020	.106	−.088	.002
	e	.142	.007	.021	−.172
Turkey					
	o	−.071	–	.036	.034
	g	–	–	–	–
	c	.245	–	−.124	−.120
	e	.041	–	−.021	−.020
Venezuela					
	o	−.039	.003	–	.036
	g	.000	−.061	–	.060
	c	–	–	–	–
	e	.013	.015	–	−.028

Table 18

Own- And Cross-Price Elasticities For Lower-Middle To Low-Income Countries

Country	Factor i	Own- and cross-price elasticities η_{io}	η_{ig}	η_{ic}	η_{ie}
China					
	o	−.005	–	−.019	.024
	g	–	–	–	–
	c	−.009	–	−.040	.050
	e	.049	–	.198	−.248
India					
	o	−.003	–	−.004	.007
	g	–	–	–	–
	c	−.021	–	−.042	.063
	e	.005	–	.012	−.018
South Africa					
	o	−.048	.025	.010	.013
	g	.063	−.033	−.013	−.017
	c	.708	−.377	−.140	−.191
	e	.378	−.194	−.083	−.100
Thailand					
	o	−.140	–	.055	.084
	g	–	–	–	–
	c	2.659	–	−1.107	−1.552
	e	.184	–	−.067	−.117

Table 19

Allen Elasticities Of Substitution For High-Income Countries

Country	Factor i	Allen elasticities of substitution			
		σ^a_{io}	σ^a_{ig}	σ^a_{ic}	σ^a_{ie}
Canada					
	o	−.101	.299	–	−.029
	g		−.891	–	.085
	c			–	–
	e				−.009
France					
	o	−.067	−.012	.178	.199
	g		−.002	.032	.035
	c			−.489	−.496
	e				−.683
Japan					
	o	−.121	−.006	.645	.238
	g		−.000	.038	.011
	c			−3.555	−1.257
	e				−.476
Italy					
	o	−.044	–	−.447	.093
	g		–	–	–
	c			−4.676	.933
	e				−.202
U.K.					
	o	−.099	.044	.213	−.950
	g		−.034	−.014	−.257
	c			−1.057	6.478
	e				−72.572
U.S.					
	o	−.043	.000	.071	.247
	g		−.002	−.009	.290
	c			−.160	1.012
	e				−64.073

Table 20

Allen Elasticities Of Substitution For Upper-Middle To High-Income Countries

Country	Factor i	Allen elasticities of substitution σ^a_{io}	σ^a_{ig}	σ^a_{ic}	σ^a_{ie}
Poland					
	o	−.249	−.080	.589	−.032
	g		−.027	.195	−.013
	c			−1.434	.089
	e				−.012
Hungary					
	o	−.129	.189	.346	−1.485
	g		−.331	−.416	1.991
	c			1.261	4.771
	e				−31.027
Mexico					
	o	−.029	.026	−.061	.401
	g		−.100	.231	.008
	c			−.614	.142
	e				−18.245
Turkey					
	o	−.155	–	.529	.082
	g		–	–	–
	c			−1.824	−.290
	e				−.056
Venezuela					
	o	−.225	−.009	–	.054
	g		−.631	–	.093
	c			–	–
	e				−.046

Table 21

Allen Elasticities Of Substitution For
Lower-Middle To Low-Income Countries

Country	Factor i	Allen elasticities of substitution			
		σ^a_{io}	σ^a_{ig}	σ^a_{ic}	σ^a_{ie}
China					
	o	−.019	–	−.034	.190
	g		–	–	–
	c			−.075	.347
	e				−1.933
India					
	o	−.011	–	−.058	.014
	g		–	–	–
	c			−.742	.232
	e				−.077
South Africa					
	o	−.071	.092	1.040	.553
	g		−.124	−1.370	−.712
	c			−15.618	−7.772
	e				−4.404
Thailand					
	o	−.206	–	3.919	.272
	g		–	–	–
	c			−109.876	−5.059
	e				−.378

Table 22

Morishima Elasticities Of Substitution For High-Income Countries

Country	Factor i	Morishima elasticities of substitution			
		σ^m_{io}	σ^m_{ig}	σ^m_{ic}	σ^m_{ie}
Canada					
	o		.198	–	−.009
	g	.145		–	.043
	c	–	–		–
	e	.025	.162	–	
France					
	o		−.004	.106	.009
	g	.021		.082	.007
	c	.095	.015		.000
	e	.103	.016	−.007	
Japan					
	o		−.004	.227	.011
	g	.032		.194	.007
	c	.221	.027		−.013
	e	.102	.008	.123	
Italy					
	o		–	.016	.097
	g	–		–	–
	c	−.263	–		.377
	e	.091	–	.022	
U.K.					
	o		.030	.211	.543
	g	.059		.173	.553
	c	.129	.007		.648
	e	−.376	−.081	1.242	
U.S.					
	o		.001	.040	.402
	g	.014		.026	.402
	c	.039	−.003		.407
	e	.098	.139	.205	

Table 23

Morishima Elasticities Of Substitution For Upper-Middle To High-Income Countries

Country	Factor i	Morishima elasticities of substitution σ_{io}^{m}	σ_{ig}^{m}	σ_{ic}^{m}	σ_{ie}^{m}
Poland					
	o		−.024	.341	−.002
	g	.039		.274	−.000
	c	.195	.105		.021
	e	.050	.006	.256	
Hungary					
	o		.128	.268	.497
	g	.173		.141	.579
	c	.259	−.020		.654
	e	−.716	.623	.987	
Mexico					
	o		.058	.079	.178
	g	.019		.122	.173
	c	−.010	.152		.174
	e	.152	.053	.110	
Turkey					
	o		–	.161	.054
	g	–		–	–
	c	.316	–		−.100
	e	.113	–	.103	
Venezuela					
	o		.064	–	.065
	g	.040		–	.089
	c	–	–		–
	e	.053	.076	–	

Table 24

Morishima Elasticities Of Substitution For Lower-Middle To Low-Income Countries

		Morishima elasticities of substitution			
Country	Factor i	σ_{io}^{m}	σ_{ig}^{m}	σ_{ic}^{m}	σ_{ie}^{m}
China					
	o		–	.020	.273
	g	–		–	–
	c	−.004	–		.298
	e	.054	–	.239	
India					
	o		–	.038	.026
	g	–		–	–
	c	−.017	–		.082
	e	.009	–	.054	
South Africa					
	o		.059	.150	.113
	g	.112		.126	.083
	c	.757	−.343		−.091
	e	.427	−.161	.056	
Thailand					
	o		–	1.162	.201
	g	–		–	–
	c	2.799	–		−1.434
	e	.325	–	1.039	

Table 25

Morishima Elasticities Of Substitution In The Industrial Sectors Of High-Income Countries

Country	Factor i	Morishima elasticities of substitution			
		σ^m_{io}	σ^m_{ig}	σ^m_{ic}	σ^m_{ie}
Canada					
	o		.162	–	−.025
	g	.050		–	.085
	c	–	–		–
	e	.011	.124	–	
France					
	o		.648	.059	−.104
	g	.453		.080	.069
	c	.275	.379		−.051
	e	.289	.248	.065	
Japan					
	o		1.710	.012	−.112
	g	.923		−.044	.730
	c	.207	1.338		.065
	e	.134	1.471	.004	
Italy					
	o		–	−.003	1.079
	g	–		–	–
	c	.301	–		.774
	e	1.065	–	.010	
U.K.					
	o		.588	.356	−.003
	g	.376		.556	.009
	c	−.434	1.286		.088
	e	.168	.329	.443	
U.S.					
	o		.032	.601	.050
	g	.026		.657	.002
	c	−.113	.234		.564
	e	.024	.001	.659	

Table 26

Morishima Elasticities Of Substitution
In The Industrial Sectors of Upper-Middle
To High-Income Countries

Country	Factor i	Morishima elasticities of substitution			
		σ^m_{io}	σ^m_{ig}	σ^m_{ic}	σ^m_{ie}
Poland					
	o		.612	−.127	.150
	g	.595		.089	−.050
	c	.372	.236		.026
	e	.445	.157	.031	
Hungary					
	o		.064	–	−.007
	g	.044		–	.012
	c	–	–		–
	e	.018	.037	–	
Mexico					
	o		.134	–	.017
	g	.011		–	.140
	c	–	–		–
	e	−.000	.153	–	
Turkey					
	o		–	.122	−.001
	g	–		–	–
	c	.112	–		.008
	e	.029	–	.091	
Venezuela					
	o		.009	–	.094
	g	.098		–	.004
	c	–	–		–
	e	.103	−.000	–	

TABLE 27

MORISHIMA ELASTICITIES OF SUBSTITUTION
IN THE INDUSTRIAL SECTORS OF LOWER-MIDDLE
TO LOW-INCOME COUNTRIES

Country	Factor i	Morishima elasticities of substitution			
		σ_{io}^m	σ_{ig}^m	σ_{ic}^m	σ_{ie}^m
South Africa					
	o		–	.023	.136
	g	–		–	–
	c	−.036	–		.195
	e	.084	–	.075	
Thailand					
	o		–	−3.085	.409
	g	–		–	–
	c	−2.654	–		−.021
	e	.759	–	−3.435	

TABLE 28

MORISHIMA ELASTICITIES OF SUBSTITUTION IN THE RESIDENTIAL SECTORS OF HIGH-INCOME COUNTRIES

		Morishima elasticities of substitution			
Country	Factor i	σ^m_{io}	σ^m_{ig}	σ^m_{ic}	σ^m_{ie}
Canada					
	o		.157	–	−.027
	g	.050		–	.078
	c	–	–		–
	e	.013	.115	–	
France					
	o		.306	–	−.031
	g	.229		–	.045
	c	–	–		–
	e	.093	.182	–	
Japan					
	o		.509	–	.486
	g	−.057		–	1.054
	c	–	–		–
	e	.053	.942	–	
U.K.					
	o		−.012	.001	.023
	g	.000		−.000	.011
	c	.000	.002		.008
	e	.001	.011	−.000	
U.S.					
	o		.314	–	−.049
	g	.060		–	.204
	c	–	–		–
	e	.012	.252	–	

Table 29

Morishima Elasticities Of Substitution
In The Residential Sectors of Upper-Middle
To High-Income Countries

Country	Factor i	Morishima elasticities of substitution			
		σ^m_{io}	σ^m_{ig}	σ^m_{ic}	σ^m_{ie}
Poland					
	o		–	–	–
	g	–		.296	.206
	c	–	.004		.498
	e	–	−.005	.507	
Hungary					
	o		.075	.445	.172
	g	.007		.409	.275
	c	−.183	−.254		1.130
	e	.034	.130	.527	
Turkey					
	o		–	.390	.549
	g	–		–	–
	c	1.109	–		−.169
	e	.861	–	.078	
Venezuela					
	o		.018	–	.000
	g	.001		–	.017
	c	–	–		–
	e	−.000	.019	–	

Table 30

Morishima Elasticities Of Substitution In The Residential Sectors of Lower-Middle To Low-Income Countries

Country	Factor i	Morishima elasticities of substitution			
		σ^m_{io}	σ^m_{ig}	σ^m_{ic}	σ^m_{ie}
South Africa					
	o		–	.416	.051
	g	–		–	–
	c	.551	–		−.083
	e	.208	–	.259	

Table 31

Morishima Elasticities Of Substitution In The Electricity Generation Sectors Of High-Income Countries

Country	Factor i	Morishima elasticities of substitution			
		σ^m_{io}	σ^m_{ig}	σ^m_{ic}	σ^m_{ie}
Japan					
	o		.125	−.004	
	g	.057		.063	
	c	.003	.117		
	e				
U.K.					
	o		−.005	.125	
	g	−.113		.233	
	c	−.155	.275		
	e				
U.S.					
	o		1.683	.011	
	g	1.704		−.009	
	c	1.503	.191		
	e				

Table 32

Morishima Elasticities Of Substitution In The Electricity Generation Sectors Of Upper-Middle To High-Income Countries

Country	Factor i	Morishima elasticities of substitution			
		σ^m_{io}	σ^m_{ig}	σ^m_{ic}	σ^m_{ie}
Mexico					
	o		.211	.000	
	g	.151		.061	
	c	.002	.210		
	e				
Turkey					
	o		.803	.169	
	g	.998		$-.025$	
	c	.833	.139		
	e				

TABLE 33

MORISHIMA ELASTICITIES OF SUBSTITUTION IN THE TRANSPORTATION SECTORS OF HIGH-INCOME COUNTRIES

Country	Factor i	Morishima elasticities of substitution			
		σ^m_{io}	σ^m_{ie}	σ^m_{id}	σ^m_{is}
Canada					
	o		−.129	.157	.963
	e	.191		.112	.687
	d	.666	.318		.007
	s	.671	.321	−.001	
France					
	o				
	e			.195	−.045
	d		.134		.015
	s		.114	.035	
Japan					
	o		−.000	1.084	−.099
	e	.002		.967	.015
	d	.041	.103		.840
	s	.008	.029	.946	
Italy					
	o				
	e			−.001	.003
	d		.001		.000
	s		.002	.000	
U.K.					
	o		.447	−1.402	2.297
	e	.600		−.875	1.616
	d	.599	.463		.278
	s	.606	.550	.184	
U.S.					
	o		−2.757	−19.692	26.617
	e	3.851		−.548	.864
	d	3.984	.104		.079
	s	3.996	.112	.059	

TABLE 34

MORISHIMA ELASTICITIES OF SUBSTITUTION IN THE TRANSPORTATION SECTORS OF UPPER-MIDDLE TO HIGH-INCOME COUNTRIES

Country	Factor i	Morishima elasticities of substitution			
		σ^m_{io}	σ^m_{ie}	σ^m_{id}	σ^m_{is}
Mexico					
	o				
	e			.503	−.166
	d		.318		.017
	s		.305	.030	
Turkey					
	o		.002	−.515	.822
	e	−.013		−.454	.776
	d	.125	.110		.072
	s	.138	.121	.048	

TABLE 35

MORISHIMA ELASTICITIES OF SUBSTITUTION IN THE TRANSPORTATION SECTORS OF LOWER-MIDDLE TO LOW-INCOME COUNTRIES

Country	Factor i	Morishima elasticities of substitution			
		σ^m_{io}	σ^m_{ie}	σ^m_{id}	σ^m_{is}
Indonesia					
	o			−.504	.865
	e				
	d	.079			.281
	s	.093		.267	
South Africa					
	o				
	e			−.454	1.068
	d		.283		.330
	s		.410	.204	